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Pasteurization of Liquid Whole Egg Under Commercial Conditions To Eliminate *Salmonella*[1]

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SUMMARY

Research on the use of pasteurization to eliminate *Salmonella* types of bacteria from egg products has been carried out by the Poultry Branch of the Production and Marketing Administration in cooperation with members of the egg-breaking industry. The results show that pasteurization can be successfully used, under processing-plant conditions, to produce liquid, frozen, and dried whole egg free of *Salmonella*. The studies demonstrated that milk-pasteurizing equipment can be used, with little or no change, for the pasteurization of liquid whole egg.

With careful attention to operating procedures, the liquid whole egg can be flash-heated to 140° F. and held at that temperature for 3 minutes to kill any *Salmonella* present without appreciably affecting the functional qualities of the egg product. Liquid egg so treated was found to be free of *Salmonella*, although many samples of the raw product contained the organisms before pasteurization.

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[1] The study on which this report is based was conducted under authority of the Research and Marketing Act of 1946. It represents a part of the research program directed to the solution of problems of a technical nature under commercial plant-operating conditions.

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INTRODUCTION

The presence of members of the genus *Salmonella* in egg products passing in commerce has caused concern among agencies interested in the public health, although the number of food-poisoning outbreaks traceable to egg products has been remarkably small. The pathogenicity of certain types of the organisms, only recently established (*4*),[3] points up the necessity of seeking ways and means to prevent the entry of such organisms into egg products or to eliminate them after they have gained entrance.

Results of previous research (*9, 10*) show that *Salmonella* contamination may be found in liquid, frozen, and dried eggs, that the type of egg being broken for freezing and drying influences the degree of contamination, and that there is no correlation between the occurrence of *Salmonella* contamination and geographical location. Naturally clean eggs are relatively free of *Salmonella*, but dirty and low-quality eggs may show four times as much contamination (*9, 2*). Washing the shell does not eliminate this type of contamination as bacteria in infected eggs are inside the shell.

As it is economically impracticable to produce frozen and dried eggs from only naturally clean eggs, and as there is no known way of segregating shell eggs on the basis of their *Salmonella* content, the most logical approach to the problem of eliminating *Salmonella* appears to be that of pasteurizing the liquid egg. To determine whether successful pasteurization could be accomplished, research was carried out in commercial plants by adapting available equipment to the requirements of the problem.

Pasteurization to reduce bacterial numbers in egg products, and to improve keeping quality, was first practiced commercially by Henningsen Brothers in 1938. Their process involved bringing vats of liquid yolk or whole egg to the pasteurization temperature by means of rotating coils filled with hot water. The senior author was privileged to study operations at their plant in the spring of 1942.

Later, continuous flash heating was employed in the production of low-moisture (2 percent) dried whole egg (*7*). McFarlane, Watson, and Goresline (*5*) pointed out that unless such flash heating is conducted at temperatures above 135° F., enormous bacterial populations are built up during several hours of operation, that by raising the temperature of operation to about 140° F. pasteurization could be accomplished and bacterial numbers markedly reduced, and that in certain equipment, temperatures as high as 150° F. could be used.

Although the flash pasteurization of liquid whole egg has been shown (*1, 3, 5, 7, 11, 12, 13*) to be a feasible operation, such treatment does not always render a product sterile (*5, 10*), and *Salmonella* types of bacteria survive (*8, 13*). Plate-type preheaters have been in use for some time in plants producing 2-percent moisture egg powder (*7*) but, under the conditions of operation, *Salmonella* types of bacteria persisted in such powder (*8*).

EXPERIMENTAL PROCEDURE

The study was directed against the problem of eliminating the *Salmonella* types of bacteria from whole-egg products; it did not encompass the whole question of bacterial destruction by pasteurization. Preliminary to this study, shell eggs were subjected to pasteurization in oil and in water to determine whether *Salmonella* types of bacteria present in the eggs could be killed. The yolks of the eggs were lightly inoculated with a live culture of *Salmonella* and the eggs were then immersed in agitated constant-temperature baths for varying periods of time. The temperatures chosen were those employed in studies on the thermostabilization of shell eggs, 130° to 144° F. In every case it was found impossible to kill the *Salmonella* and still have a marketable product. When the albumen of the egg remained clear the *Salmonella* survived, and when complete killing was obtained the albumen was opaque and firmly jelled. Therefore, it was concluded that the heat treatment of shell eggs could not be utilized to eliminate *Salmonella* contamination.

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[3] Italic numbers in parentheses refer to Literature cited, p. 15.

Research was then undertaken to determine whether *Salmonella* bacteria could be eliminated from liquid, frozen, and dried whole-egg products by pasteurization with the use of commercial equipment and under commercial operating conditions. Commercial egg products were used and no inoculations with *Salmonella* cultures were made; nor were other artificial conditions set up for any of the work. For the first part of the work, an egg-drying plant having a plate-type pasteurizer, with thermostatic controls and a redrier for the egg powder, was selected. The pasteurizer was made up of 16 sets of thin plates, the heated water passing on one side of the plate and the liquid egg passing on the other side. The water was circulated rapidly between the plates after being heated by steam in a thermostatically controlled device. The temperature of the egg going into the pasteurizer was about 40° F. and its temperature was raised to 140° during pasage through the unit. It is believed that the actual exposure to the latter temperature was less than 5 seconds.

Sampling of the various products in commercial production in the plant under study showed the presence of *Salmonella* in liquid egg whites, in liquid whole egg, in frozen whole egg used for drying, in whole-egg powder of 5-percent moisture, and in whole-egg powder of 2-percent moisture. It was found that the flash heater was being operated at approximately 135° F. In order to determine whether this equipment could be used to eliminate *Salmonella* types of bacteria, or altered to bring about their elimination, series of experimental runs were made.

FLASH PASTEURIZATION

Liquid egg from the breaking room was held in large vats in a cold room. Since the supply of liquid flowing to the drier came from one vat over a period of several hours, the bacterial content could be expected to be fairly constant. Thus, if *Salmonella* types of bacteria were present in the vat, the contamination could be expected to persist during that portion of the run in which this vat was used.

The pipeline used for liquid egg was tapped with a sampling valve at a point between the vat and the flash heater; samples taken at that point represented the raw material. Another valve was installed immediately after the flash heater; samples from that point represented pasteurized material. The egg powder coming from the sifter represented the final product. In later experiments a holding tube was installed after the flash heater, and a sampling valve was placed at the far end of this tube.

In the initial experiments the pasteurization temperatures ranged from 130° to 147° F. Temperatures of 145° and above proved impracticable for commercial plant operation. owing to the coating of the plates of the heater and the sticking of high-pressure pump valves. even though a cooling jacket on the pipeline to the pump was used. Also. it was found that, from a practical operating standpoint, 140° was the best temperature to use. Above this temperature there was coating of the equipment which necessitated occasional shutdowns for cleaning, and it was difficult to maintain good plant operation while using the higher temperatures. There was frequent operating trouble with temperatures at 145°, and occasional difficulty at 142°, but no trouble with temperatures at 140° F.

In making experimental runs, the temperature of the flash heater was set at a selected value, and samples of raw and heated liquid egg and of egg powder were taken at 20-minute intervals. As the samples of liquid coming from the flash heater were hot, and any extension of the heating period would serve to kill bacteria, the samples were cooled immediately by placing the sample bottles in cold water.

Samples of the egg products were weighed into selective bacteriological media and into sterile dilution blanks for making viable bacterial counts. Bacterial counts were made on tryptone glucose extract agar, the coliform count was made on desoxycholate agar, and *Salmonella* isolations were made by means of a series of media, including selenite-F, Kligler's iron agar, and urea broth, followed by serological identification.

It would apear to be a simple matter to demonstrate the elimination of *Salmonella* from egg products by taking samples of (1) the raw material, (2) the heated liquid, and (3) the egg powder, and showing that the bacteria in question were killed, since they were found in the first but not in the second and third samples. However, on several occasions *Salmonella* types of bacteria were isolated from egg powder when none was found in the raw or heated liquid. In other cases *Salmonella* cultures were isolated from the raw liquid but not from the heated liquid, and appeared in the dry powder. For this reason it was found necessary to run a large number of samples in order to make sure that negative results did not actually represent "skips."

Several uncontrollable factors work against the isolation of *Salmonella* types of bacteria from products known to contain them. A selective culture medium, inhibitory to other types of organisms, must be used in order to keep certain bacteria from growing to such an extent as to overshadow the *Salmonella* present. Such media are generally somewhat toxic to the organisms under study; if present in small numbers or in a weakened condition, these organisms may be killed or held in check by the selective media. On the other hand, vigorous types of other bacteria may outgrow the various *Salmonella* types despite the action of the selective medium, or they may exert an inhibitory action, thus making it very difficult to isolate the *Salmonella*. At times *Salmonella* organisms may be present in small numbers and therefore difficult to culture to a point where they can be isolated by the conventional methods used in the bacteriological field.

During the experimental runs, *Salmonella* organisms were isolated from liquid egg flash-heated to temperatures as high as 145° F. and from egg powder made from such liquid. In one run in which pasteurization temperatures ranged from 135.5° to 140°, and defrosted frozen egg was used, *Salmonella* organisms were isolated from five of seven samples of the unheated egg liquid, from seven of seven samples of the heated liquid, and from two of six samples of the egg powder. The isolations from the heated samples were made in four cases when pasteurization was being carried out at 140° F. In another run, in which fresh liquid egg was used, *Salmonella* cultures were not isolated from the raw liquid or from liquid heated to 140° F., but two out of four samples of the dried egg made from the liquid were positive. This result points to the difficulties sometimes encountered in *Salmonella* isolation, and to the necessity of carrying out extensive sampling to establish a pattern.

The total bacterial counts were markedly lowered by the heat treatment, even though exposure to killing temperatures was short. Typical examples of results from experimental runs with liquid eggs are shown in table 1. As pointed out by Winter, Greco, and Stewart (*12*), such reductions in bacterial numbers through pasteurization result in improved keeping quality of unfrozen liquid and defrosted whole-egg products.

TABLE 1.—*Bacterial counts before and after pasteurization of liquid whole egg in commercial equipment at specified temperatures*

Experimental run	Flash pasteurizing temperature	Bacterial count—		Coliform count—	
		Before pasteurization	After pasteurization	Before pasteurization	After pasteurization
	°*F.*	*Number*	*Number*	*Number*	*Number*
No. 1	136	144, 000	25, 000	5, 300	1, 000
	140	91, 000	16, 800	6, 600	150
	140	85, 000	17, 400	6, 600	200
	145	74, 000	15, 000	5, 300	0
	145	68, 000	15, 000	4, 600	0
No. 2	136	170, 000	11, 000	12, 000	400
	140	230, 000	15, 000	28, 000	300
	140	330, 000	23, 000	20, 000	0
	145	510, 000	25, 000	60, 000	0
	145	240, 000	27, 000	24, 000	0
No. 3	140	1, 390, 000	39, 000	67, 000	6, 000
	140	344, 000	31, 000	51, 000	600
	145	280, 000	14, 000	11, 000	0

FLASH PASTEURIZATION WITH 30-SECOND HOLDING

As experimental results from the use of the flash pasteurizer showed that the heating of the liquid egg had not been carried out long enough to eliminate *Salmonella*, a second series of experiments, using a holding tube to extend the time of contact, was set up. This tube consisted of lengths of dairy-type sanitary tubing inserted between the flash pasteurizer and the high-pressure pump. The tube extended the time of exposure to the heat to approximately 30 seconds. With this equipment, the *Salmonella* isolations from the heated liquid and the powder were fewer than when the flash pasteurizer was used alone, but several liquid samples were positive, even when heated to 140° F. and passed through the holding tube. This demonstrated that pasteurization at 140° followed by a 30-second holding period could not be depended on to render liquid whole egg free of *Salmonella* contamination.

Flash Pasteurization With 2-Minute Holding

To further lengthen the period of contact, the experimental activity was shifted to another egg-drying plant having a plate-type flash pasteurizer and a tubular holding device known as a Peebles heater. This device consisted of a water-jacketed shell through which 48 tubes $^{15}/_{16}$-inch in diameter passed. The tubes were 60 inches long, and the hinged end plates of the device were so arranged that the liquid passed through eight of the tubes at a time, thus making six passes of the liquid egg through the heater. The water in the jacketed shell was circulated from the jacket of the plate pasteurizer, making it possible to maintain the original temperature in the liquid throughout the pasteurizing and holding periods. The temperature differential between the jacket and the heated liquid egg was 2° F., and there was a temperature rise of only 0.5° during passage through the holding device. The rate of pumping of liquid egg through the pasteurizer-holder system was approximately 3,000 pounds per hour. Calculations from measurements of the system showed that the holding time at this rate of flow was 1 minute and 59 seconds, or approximately 2 minutes.

Sampling valves were installed in the liquid line for sampling raw, pasteurized, and pasteurized and held material. In experimental trials the temperature was varied from 145° downward to 135° F. The higher temperature runs were made first so that contaminating bacteria would be kept to a minimum. In changing from a lower temperature (135°) to a higher one (145°), the contamination escaping the killing action of the heat persists in a system for some time before the effect of the higher temperature is observed. By reversing the process the contamination in the system is kept at a minimum, because as the temperature is lowered the bacterial count of the system becomes constant more quickly.

When *Salmonella* types of bacteria were found in the raw material in the experimental runs, positive samples were occasionally found in the material that had passed through the pasteurizer. However, samples of material which had passed through both the pasteurizer and the holder were positive for *Salmonella* only when the equipment was being held at a temperature of 135° F. In these particular runs all samples of liquid egg heated and held at temperatures of 138° and above were negative for *Salmonella*, and the powder resulting from the drying of such liquid was negative. However, the number of samples taken at any one temperature was believed to be insufficient as a basis for definite conclusions.

Later in the year another trial run was made in the same egg-drying plant, using the same equipment and methods. The liquid whole egg was not dried; it was packed in 30-pound tins, and frozen. Because the high-pressure pump was not in operation and there was a free flow in the pipeline, the rate of flow of liquid egg was somewhat greater than in the previous experimental runs. Based on 6 hours and 20 minutes of operation, the holding period, or length of time the liquid was in the holding device, was 1 minute and 40 seconds. As the liquid was to be frozen, the pasteurized product was passed through cooling plates in one end of the pasteurizer unit and the temperature was reduced to 60° F. before placing the product in the cans. Experimental samples were frozen for later studies on the effect of the various pasteurizing temperatures on the functional quality of the egg.

According to a private communication from Iowa State College, on the results obtained when spongecakes were made with these frozen eggs, there was no marked alteration of the foaming properties of the eggs pasteurized at temperatures ranging from 135° to 145° F. and then frozen. This is in agreement with the reports of Miller and Winter (*6*) and Stewart (*11*).

During this experimental run 14 sets of samples were tested for the presence of *Salmonella*. Heating temperatures ranged from 135° to 145° F. Only two positive samples were found, one a raw sample and the other liquid coming from the pasteurizer at 140°. All samples of product coming from the holding device were negative for *Salmonella*. It was impossible to continue this study because the plant closed for the season.

At the beginning of the egg-breaking season the following spring, the study was resumed. The same equipment for heating and drying was used; the holding time was approximately 2 minutes. As previous sampling had been at several different temperatures, it was deemed desirable to make extensive samplings at one temperature of operation to determine what results could be expected under continuous full-scale plant production. The holding tank for egg liquid held several hundred gallons, which permitted several hours of operation on the same batch of liquid. Therefore, the bacterial content could be considered rather uniform over a considerable period of time. Samples were taken at hourly intervals during the operation of the plant for an 8-day period. The equipment was operated at 140° F. throughout this period. During this time 78 sets of samples were taken, each set representing raw material, pasteurized, pasteurized and held liquid, and egg powder. Of the raw samples, 37 percent were *Salmonella* positive. The numbers of *Salmonella*-positive samples obtained in this series were: Raw material, 29; pasteurized, 25; pasteurized and held, 1; and egg powder, 3. From these results it may be concluded that the incidence of *Salmonella* contamination was markedly reduced by the treatment of heating and holding for approximately 2 minutes, but that it was not eliminated in all cases, and that a somewhat longer holding period must be employed to guarantee a *Salmonella*-free product.

Flash Pasteurization With 3-Minute Holding

EQUIPMENT AND OPERATION

In order to obtain holding periods of more than 2 minutes, the research activity was moved to a third commercial plant. The equipment in this plant consisted of two plate pasteurizers and banks of sanitary piping which could be connected in various lengths to obtain any desired period of holding. One pasteurizer unit was operated for 4 hours; then the second unit was placed in operation while the first one was being cleaned.

In this plant the rate of flow of egg liquid through the equipment was approximately 5,000 pounds per hour and, accordingly, a temperature differential of 6° to 7° F. between the water jacket and the egg medium was necessary in order to obtain a selected temperature in the flash heater. Such a differential made it undesirable to use the hot water for jacketing the holding tubes; this would have produced an additional temperature rise of about 5° in the egg. The exposed holding tubes were therefore covered with a heavy tarpaulin to conserve heat and to eliminate air drafts. Under such an arrangement the temperature drop in the egg was approximately only 1° during a 3-minute holding period.

The rate of flow of egg liquid was controlled by the speed of the sanitary pump forcing the liquid through the unit. By choosing a holding tube with a length corresponding to a certain holding period, and by changing the speed of the pump slightly, an exact holding period could be obtained. However, any change in the pump speed by plant personnel resulted in a shorter or longer holding period, necessitating frequent check measurements to maintain exact holding periods. The rate of flow and the length of the holding periods were determined by means of measurements of the entire pasteurizing and holding system and the length of time necessary to fill calibrated egg vats. The two pasteurizing units were of different makes, with slight differences in construction, but the operation and performance were essentially the same.

While in use there was a steady buildup of a film of coagulated egg on the surface of the pasteurizer plates, and to some degree on the surfaces of the holding tubes. The film was never allowed to become thick enough to interfere seriously with the operation of the equipment, but it was necessary to increase slightly the temperature differential between the water jacket and the egg to compensate for the film's insulating effect. Also, the rate of flow decreased slightly during use owing to the increase in resistance in the system. The film adhered to the surfaces with a firm bond, and during cleaning a detergent and thorough brushing were necessary to obtain a clean, smooth surface.

The most critical point in the efficient pasteurization of the liquid whole egg was in the control devices. At one time during the study, a steam-control valve adjustment became loose, causing a wide fluctuation in temperature which made it impossible to maintain an even pasteurization temperature.

At another time the air-actuating valve of the electrical control device became clogged, resulting in a temperature fluctuation of about 10° F. These experiences pointed to the necessity of proper temperature controls, kept in correct adjustment.

Extreme fluctuations in temperature cannot be tolerated in such an operation. If the temperature is allowed to fall more than 1° F., the efficiency of pasteurization is decreased. Successful pasteurization is based on a critical time-temperature relationship; if the temperature is allowed to increase, there is danger of coagulating the egg and damaging the functional quality of the egg products. In the operation of an efficient pasteurizing system it is necessary to subject all material being treated to the lethal temperature for the correct period of time. Any product not thus treated has not been properly pasteurized and the purpose of the operation is defeated.

One of the defects of plant operation was the lack of segregation of the improperly pasteurized product from that which had undergone adequate treatment. At the beginning of each run there was always a period when a full flow of product was going through the entire system, yet the pasteurizer was not up to proper temperature. Also, at the period of change-over from one pasteurizing unit to the other, a considerable quantity of product was passed through the equipment without being subjected to pasteurizing temperatures.

The product was sampled for experimental purposes only when the entire operation was in balance and the pasteurization was being properly done. This procedure provided a means of determining the efficiency of the operation. At hourly intervals a sample of the raw material flowing to the pasteurizer was taken and at a time approximately equivalent to the holding time of the equipment the pasteurized samples were obtained. Because the heated egg was passed through a cooling unit after the holding period, it was not necessary to cool the sample bottles immediately, as had been done in the previous research. However, to prevent any subsequent bacterial growth the samples were packed in snow or crushed ice as soon as they reached the laboratory. At the time of taking the samples the temperatures of the water jacket, the flash-pasteurized liquid, and the pasteurized and held liquid were recorded. A period of at least 20 minutes was allowed to elapse after a change-over of pasteurizers or any irregularity of operation before a sample was taken. The time interval during which the samples were taken at each sampling valve was approximately 30 seconds. Thus the samples represented approximately 0.83 percent of all the liquid egg passing through the equipment. The amount of reserve liquid egg on hand at any time was generally less than that necessary for 1 hour of operation. Accordingly, each hourly sample represented new egg liquid and not the composite of a large reserve tank.

To determine the presence or absence of *Salmonella* at set intervals, the liquid samples were weighed into bottles containing selenite-F culture medium and incubated at 98.6° F. (37° C.) for 16 hours. At the end of that time the enriched culture was streaked onto plates of selective culture media and carried through the customary bacteriological procedure for the isolation and identification of *Salmonella* types of bacteria.

It was believed that the results from 100 sets of hourly samples of raw and pasteurized liquid egg would indicate the effectiveness of the pasteurizing method in eliminating the *Salmonella* contamination. The egg-drying plant was operating on a 24-hour schedule and on a 5-day week. To have a record of the full operation and to make a comparison of the results from the various shifts, the sampling was carried out around the clock. The only hourly intervals not covered were those in which the irregularity of operation made it advisable to disregard them.

The temperature chosen for this work was 140° F.: the holding time selected was 3 minutes, as it had been demonstrated that a 2-minute holding time was insufficient. Frequent checks were made of the length of the holding interval, especially after the changing of pasteurizer units, and the temperature was checked at each sampling.

The first 10 samples taken represented pasteurized material only, as it had been impossible to install a sampling valve in the raw-material pipeline. After this valve was installed, all samples represented both raw and pasteurized liquid. Some difficulty was encountered in maintaining the chosen temperature (140° F.) because of fluctuation in the operation of the control devices; however, the drop in temperature below 140° was seldom more than 1° F.

RESULTS OF EXPERIMENTAL PASTEURIZING RUNS

140° F. with holding time of 3 minutes:

As soon as the sampling valves were in place and the entire pasteurizing system was checked for constancy of operation, the pasteurizing runs were started. For the first series of sampling, a flash-pasteurizing temperature of 140° F., followed by a 3-minute holding period, was selected. Samples were taken at hourly intervals except when plant operation was interrupted or temperatures were not within the selected range. In this series, 150 sets of samples representing 150 hours of continuous commercial operation were taken.

The number of raw samples found positive for *Salmonella* bacteria was 32, or 21.3 percent of the total number of raw samples taken. All the 150 samples of pasteurized and held liquid were negative for *Salmonella*. Thus, during 150 hours of continuous plant operation, the pasteurization at 140° F., with a holding time of 3 minutes, was found adequate to eliminate the *Salmonella* types of bacteria.

During this experiment 9.33 percent of the temperature readings of the pasteurized and held material fell more than 1° below the selected temperature of 140° F., but in no case did any temperature reading fall more than 2° below 140°.

140° F. with holding time of 2 minutes:

It was believed desirable to recheck the 2-minute holding period under the particular conditions existing in this egg-drying plant. Accordingly, the length of the holding tube was reduced and the pump adjusted to a rate of flow equal to a 2-minute holding period. The flash temperature remained at 140° F. for this series of runs.

Samples were taken at hourly intervals for 66 hours of commercial plant operation. Of the 66 raw liquid samples, 12 were positive for *Salmonella*, or an incidence of 18.1 percent. None of the 66 pasteurized and held samples was positive for *Salmonella*.

To this group of samples, 16 were added from a 142° F. series, owing to the fact that a drop in temperature of pasteurization during that run resulted in temperature readings of only 140°. By adding these 16 samples pasteurized to 140° to the 66 samples, a total of 82 hours of operation was represented. Of the total number of raw liquid samples, 18.2 percent were positive for *Salmonella*, and all pasteurized samples were negative.

Although no positive *Salmonella* cultures were obtained in this series of pasteurized samples, it was evident from the appearance of bacterial culture plates and differential media that the effectiveness of the pasteurization was not as adequate as that which employed the 3-minute holding period. Bacterial colonies of the coliform and paracolon groups were found more frequently during the culturing of the 2-minute holding series than during the culturing of the 3-minute holding series. This finding was interpreted to mean that under the conditions in the plant at the time of the study the 2-minute holding time was adequate for pasteurizing the liquid egg, but that the safety factor was almost nonexistent. Bacteriological evidence pointed to a much broader safety factor in the 3-minute holding period, as bacteria of the two groups were seldom found in pasteurized samples of this series.

142° F. with holding time of 2 minutes:

In order to determine whether 142° F. for 2 minutes would be adequate or desirable in the pasteurization of liquid whole egg, a plant run of 42 hours was made. Difficulty was found in holding the selected temperature. Of the 42 temperature readings, 17, or 38 percent, were more than 1° below the selected temperature, and some readings were 4° below the 140° temperature. Because of this fluctuation in temperature, only 25 sets of samples were truly representative of the 142° series. Of this group, there were two *Salmonella*-positive raw-liquid samples, and all pasteurized and held samples were negative for *Salmonella*. Here again there was evidence of a very small safety factor in the 142° temperature with a 2-minute holding period, as bacteria of the coliform and paracolon groups were in evidence on many of the differential culture plates.

Samples of raw liquid and pasteurized liquid for the 2- and 3-minute holding periods at 140° F. and for 2 minutes at 142° were frozen and forwarded to the Western Regional Research Laboratory of the Bureau of Agricultural and Industrial Chemistry for functional studies. Baking studies were carried out and the Laboratory has reported, in confirmation of the literature, that under some cake-making conditions differences in functional properties could be detected, while under other conditions no differences were detected. In every case the alterations were small; therefore it seems likely that pasteurized eggs will be suitable for many, if not all, industrial uses for which unpasteurized eggs are now used.

CONCLUSIONS

Conclusions from the results of the study on which this report is based are as follows:

1. Flash pasteurization at temperatures as high as 145° F. is not sufficient to kill *Salmonella* types of bacteria that may be present in the liquid egg.
2. A temperature of 140° F. is the most dependable temperature under existing commercial plant operation, because of easy attainment, less fluctuation, less frequent and easy cleaning of equipment, and acceptance by plant personnel.
3. Holding periods up to 2 minutes when used with a flash-pasteurizing temperature of 140° F. are not satisfactory for producing a *Salnonella*-free liquid whole egg.
4. A holding period of 3 minutes following flash pasteurizing to 140° F. is satisfactory for the elimination of *Salmonella* types of bac-

teria from liquid whole egg, and this holding period appears to provide a margin of safety in operation.

DISCUSSION AND RECOMMENDATIONS

The pasteurization technique at present appears to be the most feasible method for the elimination of *Salmonella* types of bacteria from liquid whole egg. Mechanical equipment designed for the pasteurization of milk can be used for the pasteurization of liquid whole egg without alteration. The narrow limits of temperature that can be used present the greatest difficulty in carrying out the pasteurization. Temperatures below 135° F. do not kill bacteria and may even stimulate the growth of certain types. Temperatures above 145° produce excessive coagulation of the egg protein, which results in loss of heating efficiency and stoppage of the flow of egg.

The study shows that by the use of accurate temperature controls and the employment of reasonable and attainable operating techniques, *Salmonella* bacteria can be eliminated. Moreover, this goal can be attained under commercial plant operating conditions and with untrained labor. The temperature of 140° F., with a holding time of 3 minutes, is slightly in excess of that indicated by Winter, Stewart, McFarlane, and Solowey (*13*) for killing the *Salmonella* types of bacteria most commonly found in eggs (*10*) and therefore provides a margin of safety of operation.

Although satisfactory results can be expected from the pasteurization method, observations on plant operations point to the desirability of incorporating the following recommendations into the operating program:

1. *Installation of an educational program.*—A thorough understanding by plant personnel of the purpose of pasteurizing treatment and the necessity of maintaining a specific temperature is essential. It should be the understanding of both management and operating personnel that pasteurization can in no way take the place of good raw material or good sanitary practices. It is necessary to point out that certain bacteria grow rapidly at tempeartures up to about 130° F., that equipment can become a bacterial incubator at these temperatures, and that it is necessary to maintain a constant temperature of 140° to be assured that the bacteria are killed. Unless fully aware of the necessity of maintaining a given temperature in the pasteurizer jacket, the machine operator may be inclined to carry as low a temperature as possible in order to avoid mechanical and cleaning difficulty. This tendency was observed in certain instances, particularly when attempts were made to use temperatures of 145° to 147°. Because of mechanical and operational difficulties it is believed that the highest practical temperature for commercial use is 142°, and that better cooperation from personnel and more consistent operation will be obtained at 140°. It is also essential that personnel realize that the rate of flow of liquid governs the holding time and that indiscriminate changes in pump speed or valve openings result in defeating the purpose of the pasteurization as surely as does the change in temperature.

2. *Installation of accurate temperature-control equipment and a program to keep it in adjustment.*—In certain plants equipment was

found which would not hold adjustment within 10° of the 140° F. setting, because of the faulty or poorly adjusted control devices. In these plants the temperature was largely a manual operation of readjustment at 20- to 30-minute intervals. Under such conditions it is impossible to continuously produce a *Salmonella*-free product.

3. *Installation of continuous temperature-recording devices to provide permanent records of temperatures used.*—The purpose of pasteurization is to kill any *Salmonella* that may be present, and the plant management must have a complete record of the temperature of pasteurization, for every period of plant operation, before it can be assured that this purpose has been accomplished. When workmen know that a record of their work is being made they are more likely to be careful in seeing that the temperature and the plant efficiency are maintained.

4. *Segregation of all unpasteurized products.*—If a pasteurization program is to be effective, there must be assurance that *all* the product going into trade channels has been properly treated and made free of *Salmonella* contamination. At the start of each run there is a period in which a considerable quantity of material is produced before the proper pasteurizing temperature can be attained. Provision should be made to bypass such liquid egg back to the original holding vat until the temperature of 140° F. has been reached and *is being maintained.* Unless this is done, several hundred pounds of product which has not been made free of *Salmonella* contamination may pass through the entire system and be marketed with the properly treated lot. The same provision applies to products manufactured at any other time when the proper temperature is not being maintained. When it is found that something is wrong in the system, the plant should be shut down and all the material produced during the "off" period should be returned to the holding vat, or segregated and not included in the *Salmonella*-free commercial lot.

The best and surest way of accomplishing such uniform operation is through the use of an automatic flow-diversion valve. This piece of equipment allows liquid to flow into the production line only when a specific temperature is reached and maintained. Should the temperature suddenly drop during the run, this valve automatically diverts the flow away from the production line, and remains in the off position until the temperature returns to normal. This device is used throughout the milk industry for controlling pasteurization, and its use in egg pasteurization in a plant in Ireland has been described (*1*).

5. *Establishment of a systematic operating schedule.*—Written instructions should be posted for each phase of the plant work. As each man comes on duty he should be able to determine the objectives for the day and the exact manner in which they are to be attained. Personnel cannot be expected to use initiative in maintaining operating schedules unless they understand what is expected.

Written reports of work performed should be required of each department in the plant. Not only will this acquaint management with the plant performance, but it will alert the employee to the accuracy of each operation and record.

Figure 1 shows suggested pasteurization equipment which has automatic temperature controls and a flow-diversion regulator.

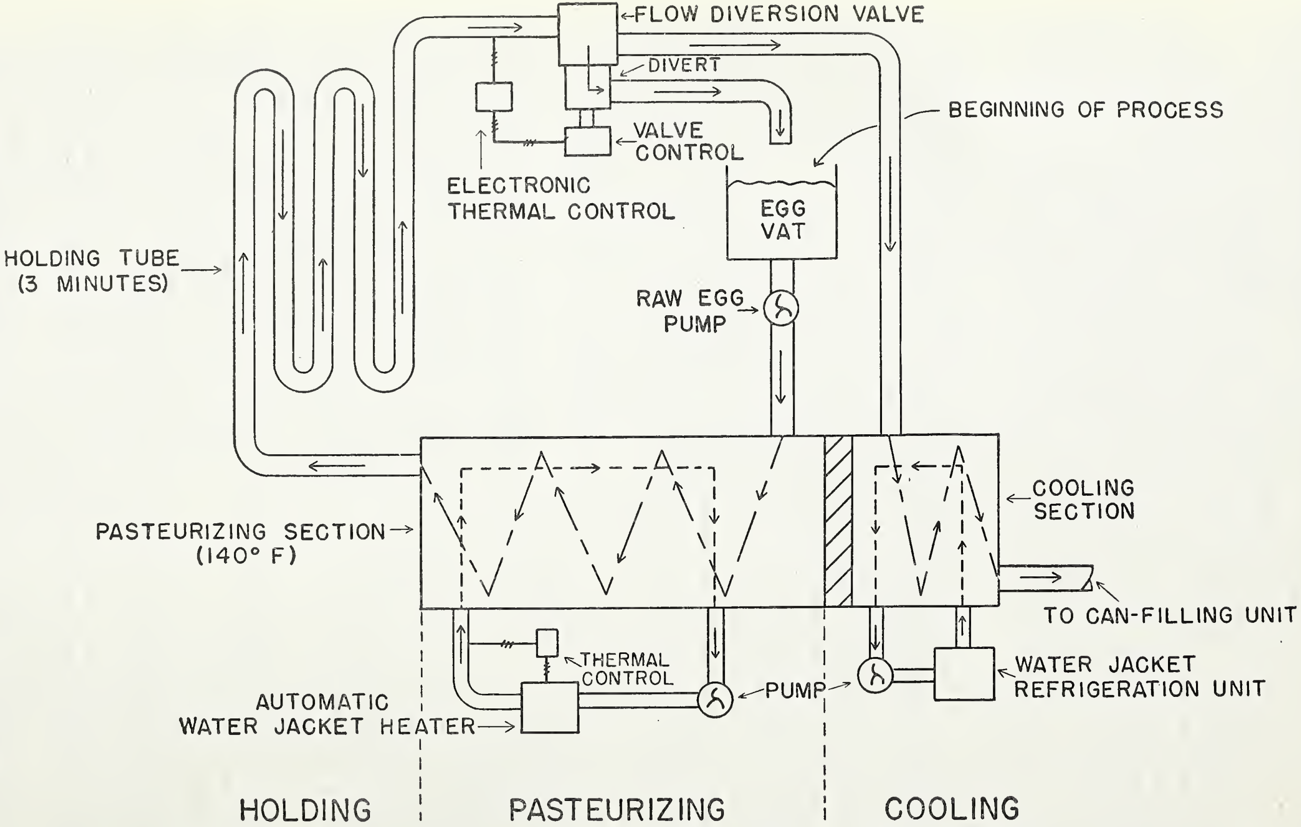

FIGURE 1.—Layout of egg-pasteurizing equipment having automatic controls.

The equipment, maintenance, and operation of a system to produce a *Salmonella*-free product necessitates extra plant expense, and if the purpose for which the treatment is carried out is not accomplished, the extra expense is wasted With proper equipment and a full understanding of the problem by both management and operating personnel the production of *Salmonella*-free whole-egg products can be made a practical commercial-plant operation.

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